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Safety Evaluation of Live Line operators of 1200 KV UHV AC Exposed to Electric and Magnetic Fields

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***Abstract*—This paper presents the study of assessment of external electric and magnetic field exposure to live line operator of 1200 KV, Ultra High Voltage (UHV) AC proposed line in India. Single circuit (S/C) and double circuit (D/C) power lines are considered for the assessment. Combination of charge simulation and image method is adopted for evaluation of extremely low frequency (ELF) electric fields where as Ampere law is used for magnetic fields. Analysis is carried out using MATLAB software . The assessment of ELF exposure to line operator has been carried out for various scenarios. These assessed values of electric and magnetic field (EMF) exposures are compared with standard allowable limits set by various International Standards. Moreover, the safety of general public living at the edge of right of way (ROW) and 15 m away is evaluated. The objective of the study is to create awareness about the power frequency EMF radiations and its health issues among the power engineers, line operators , general public's and to electricity utilities, the government to enforce the regulations.**

***Index Terms*—electric field, magnetic field, exposure limits, extremely low frequency.**

I. Introduction

Indian power sector is growing at an accelerated pace. To meet the long term power transfer need over a large geographical area, India has adopted 1200 KV Ultra High Voltage (UHV) AC system. The test substation 400/1200 KV has been installed at Bina in Madhya Pradesh, India with 1.1 Km long single circuit (S/C) and 0.8 Km double circuit (D/C) lines[1].The first line is planned to construct from Vardha to Aurangabad having length 382 Km [2]. With increase in system voltage, there is increase in the associated electric and magnetic fields (EMF) and hence, need to examine its impact on design of lines, safety of live line operator's, behaviour of humans in and around the power lines.

Exposure of humans to Extra High Voltage (EHV) /UHV line EMF of extremely low frequency (0-3 KHz), hereafter we can call power frequency 50Hz, becomes a hot topic of controversial. There are several research publications and reports indicating that prolonged exposure to EMF have health risk [3,4,5]. It is reported that the Soviet switchyard workers were exposed to 50-Hz electric field had suffered health problems such as headaches, fatigue, reduced sexual potency, and a number of other changes among a high electric-field exposure class as compared with a low exposure class [6]. Quantitative report of long term effect EMF is published in several countries [7-9].Many studies have been reported that children living near transmission line in and around right of way (ROW) had higher cancer and leukaemia incidence than living elsewhere [10].

Many organizations and countries have developed standards and guidelines for permissible limit of EMF exposure levels. These include International Commission on Non-Ionizing Radiation Protection (ICNIRP) [11]. Bonneville Power Administration (BPA) in North America [12]. The Institute of Electronic and Electrical Engineers (IEEE) [13-14] and the American Conference of Governmental Industrial Hygienists (ACGIH) [15].

This paper presents EMF produced by S/C & D/C 1200 KV UHV AC lines for various line operator scenarios. Magnetic field is analysed for full line load current I =3800A. A combination of charge simulation and image method is adopted for evaluation of electric field where as Ampere law is used for magnetic field. Matlab software is used for the analysis. The exposed EMF values are compared with standard limits of exposure published by ICNIRP, IEEE, and ACGIH for live line operator at various scenarios and general public's living in and around ROW.

The remainder of this paper is organized as follows. Systems data and various work scenarios are given in II. The theory of calculation of EMF is depicted in III followed by Emf's analysis in IV. The comparison of EMF with international standards is listed in V, whereas, the concluding remarks are drawn in VI.

II. System Data

The power lines considered for the analysis are of 200KV, AC 8000 MW, 3800 A. Photographs of S/C horizontal and D/C vertical tower are shown in figure1. Single and double circuit conductor configuration along with octagonal bundle conductor is depicted in figure 2 and 3 respectively. Distance between two bundle conductor is denoted by 'S' and 'H' is the conductor height above ground. All the sub-conductors of a bundle are uniformly distributed on a circle of radius 'R' as shown in fig.3.The spacing between adjacent sub-conductors is termed as 'Bundle Spacing' and denoted by B.

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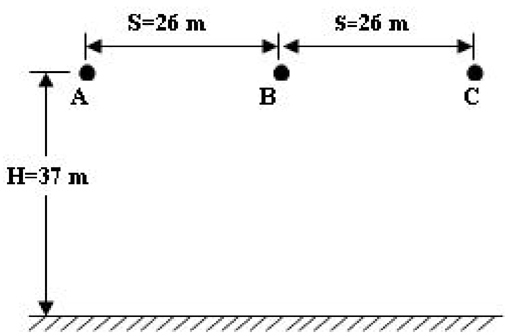
A bundle of ‘n’ sub-conductors can be replaced by a single conductor having equivalent radius known as geometric mean radius (GMR) or simply equivalent radius r_{eq} and is given [16] by

$$r_{eq} = R\,(n.r/R\,)^{1/n} \quad (1)$$

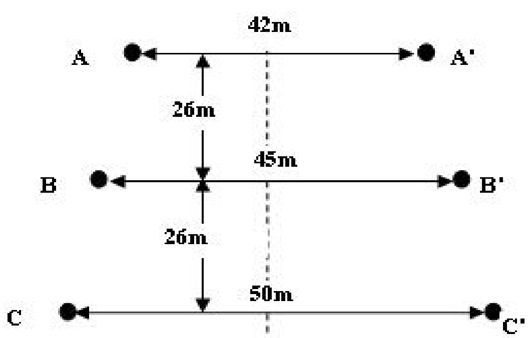
(a)

(b)

Figure 1. 1200 KV towers used at test substation Bina (a) S/C Horizontal t ower (b) D/C Vertical tower.



(a)



(b)

Figure 2. Conductor configuration (a) single circuit (b) double circuit

Where,

R = bundle radius = $B/2\,\sin(\pi|n)$

n = number of sub conductors in bundle

r = radius of each sub conductor

Detailed line data is listened in table I & II. MATLAB software is used to calculate the electric field strength (E) and magnetic flux density (B) at 50 Hz for both S/C and D/C configuration for different scenarios.

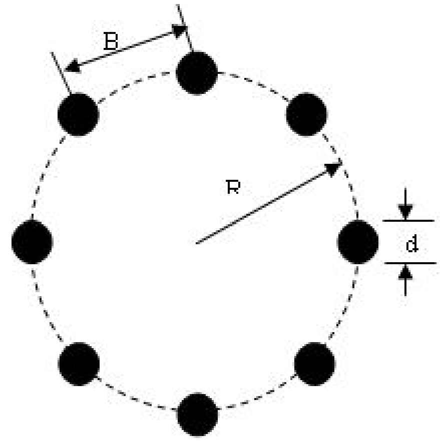


Figure 3. Octagonal bundle conductor

TABLE I: Transmission Line Data for s/c Horizontal Configuration

Description	Qty/ name	Unit
Right of way (ROW)	92	m
Bundle conductor type	Bersimice / moose	--
Bundle radius R	60	cm
Sub conductor diameter d	4.63	cm
Sub conductor spacing B	46	cm
Number of sub conductors in bundle n	8	--
Phase spacing S	26	m
Minimum ground clearance at mid span	25	m
Conductor height above ground at tower. Phase A, B, C	37	m

TABLE II: Line Data for d/c Vertical Configuration

Description	Qty/ name	Unit
Right of way (ROW)	92	m
Bundle conductor specifications are same as in table I		
Minimum ground clearance at mid span	25	m
Phase spacing S, horizontal	–	--
• Phase A- A’	42	m
• Phase B- B’	45	m
• Phase C- C’	50	m
Conductor height above ground at tower	–	--
• Phase A- A’	98	m
• Phase B- B’	72	m
• Phase C- C’	46	m

The various scenarios used for the study are -

1. operator is working at earth level in mid span .
2. working at 4 m high on ladder in mid span.
3. operator is working around the tower at earth level.
4. working at 4 m high on ladder at tower.
5. public’s living at the edge of ROW at mid span
6. public’s living at 15 m away from ROW.

II. System Development

System theory developed is highlighted in this section, using combination of charge simulation and image method for evaluation of electric fields strength (KV/m) where as

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Ampere law is used for magnetic flux density (μT) [16-18]. MATLAB software is used for field assessment.

A. Electric Field

Electric field strength of power lines is mainly depends on magnitude of system voltage /charge. Trees, tall vegetations, building materials act as a shielding and greatly reduce field strength of power lines. Caola et al [19] reported that the electric field strength inside the brick home near 500 KV AC line was eight times less than that exist outside. Fig.4 presents 'm' phase line configuration for charge calculation. Let us consider the 'm' bundle conductors above ground with their mirror images below ground. If q is the charge on bundle conductor and V is the line to ground voltage, then

$$|q| = |P|^{-1}\ |V| \tag{2}$$

Where, $|q|$ = column vector of charge on each conductor. $|V|$ = column vector of potential of the bundle conductor. $|P|$ = n x n matrix of Maxwell's potential coefficient of conductors.

$$\text{Self coefficient,}\quad P_{ii} = \frac{1}{2\pi\varepsilon}\ln\left(\frac{2H_i}{r_{eq}}\right) \tag{3}$$

$$\text{Mutual coefficient,}\ P_{ij} = \frac{1}{2\pi\varepsilon}\ln\left(\frac{l_{ij}}{a_{ij}}\right) \tag{4}$$

Where

H_i = height of conductor i above ground

l_{ij} = distance between conductor i above ground and image of conductor j below ground.

a_{ij} = aerial distance between conductor i and j

$\varepsilon = 8.85\ \times 10^{-12}$ F/m where ε is the permittivity of the air.

r_{eq} = equivalent bundle conductor radius,

i, j = 1, 2, 3, ... n

Fig. 5 depicts the line conductor i having coordinates (x_i , y_i) with charge q and its mirror image having charge –q on it. Electric field is to be evaluated at point P (x, y). Its horizontal and vertical components are given by

$$E_h = \frac{(x - x_i)}{D_i^{\,2}} \tag{5}$$

$$E_v = \frac{(y - y_i)}{D_i^{\,2}} \tag{6}$$

$$\text{Where,}\quad D_i^{\,2} = (x - x_i)^2 + (y - y_i)^2 \tag{7}$$

Similarly, field components due to image charge of conductors are given by

$$E'_h = \frac{(x - x_i)}{D'^{\,2}_i} \tag{8}$$

$$E'_v = \frac{(y - y_i)}{D'^{\,2}_i} \tag{9}$$

$$\text{Where,}\quad D'^{\,2}_i = (x - x_i)^2 + (y + y_i)^2 \tag{10}$$

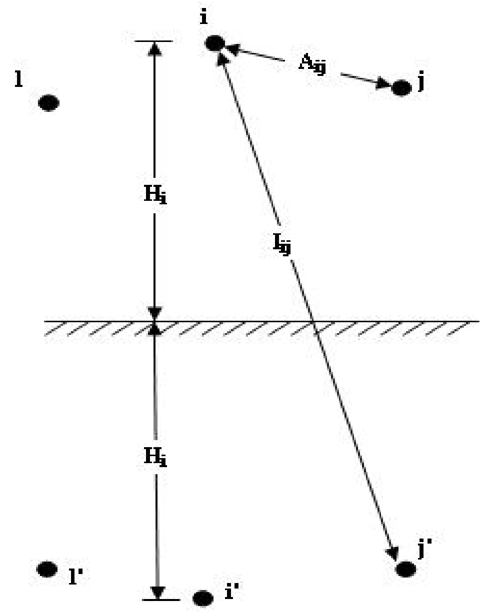

Figure 4. line configuration for charge calculation of m phases

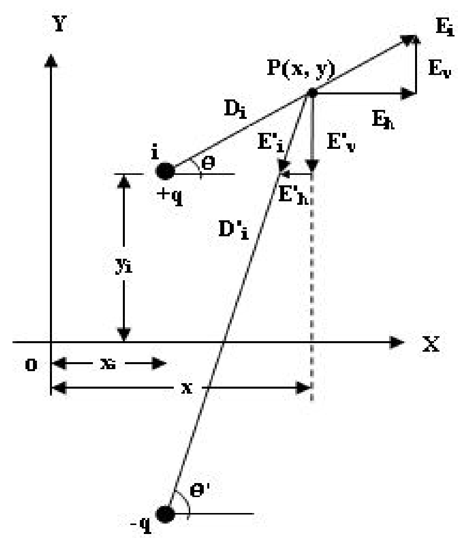

Figure 5. Electric field calculation at point P near line conductor.

Summation of horizontal components and vertical components due to m phases at any point 'P' ,

$$E_{hm} = \sum_{i=1}^{m} \frac{x - x_i}{(x - x_i)^2 + (y - y_i)^2} - \frac{x - x_i}{(x - x_i)^2 + (y + y_i)^2}$$

$$E_{vm} = \sum_{i=1}^{m} \frac{y - y_i}{(x - x_i)^2 + (y - y_i)^2} - \frac{y + y_i}{(x - x_i)^2 + (y + y_i)^2}$$

The total electric field strength is obtained by phasor addition of horizontal and vertical components.

$$E = \left[E_{vm}^{\,2} + E_{hm}^{\,2}\right]^{1/2} \times V \tag{11}$$

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E_{vm} & E_{hm} are the vertical and horizontal components of electric field. V is the line to ground voltage in KV.

B. Magnetic Field

Magnetic field strength of power lines is mainly depends on line loading. Magnetic field strength of home appliances such as TV, kitchen range at 0.3 m , is around 4 μT(40 mG). However, at 1.5m for most of the appliances, average magnetic strength is only 0.1 μT (1 mG). Trees, tall vegetations and building material do not shield the magnetic fields strength and hence, power lines can be the dominant source of magnetic fields found throughout homes near the lines[20-21].

Fig. 6, shows the line conductor carrying current I at coordinate (x_i, y_i) and its mirror image below ground with current –I . The magnetic field at point P (x, y) is to be evaluated.

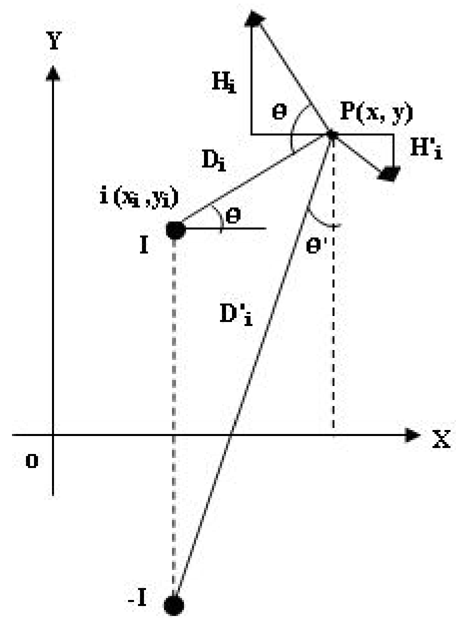

Figure.6 Calculation of magnetic field at point P near line conductor.

The magnetic field of a long straight current carrying conductor using Ampere's Law is given by

$$H_m = I/2\,\pi\, D \tag{12}$$

Where,

H_m is magnetic field strength in Ampere/ meter (A/m);
I is the current flowing through the conductor (A);and
D is the distance between the centre of bundle conductor and point where field is interested.

The summation of horizontal component and vertical component of magnetic field strength at any point 'A' due to m phases,

$$H_{hm} = \sum_{i=1}^{m} \frac{y - y_i}{(x - x_i)^2 + (y - y_i)^2} - \frac{y + y_i}{(x - x_i)^2 + (y + y_i)^2}$$

$$H_{vm} = \sum_{i=1}^{m} \frac{x - x_i}{(x - x_i)^2 + (y - y_i)^2} - \frac{x - x_i}{(x - x_i)^2 + (y + y_i)^2}$$

The total magnetic field strength H_t,

$$H_t = \left[{H_{hm}}^2 + {H_{vm}}^2\right]^{1/2} \times I/2\,\pi \tag{13}$$

Magnetic field exposure technology usually refers the magnetic field density B given by

$$B = \mu_0 . H_t \tag{14}$$

where, B is the magnetic field density in Gauss (G) or mG and $\mu_0 = 4\,\pi \times 10^{-7}$ Henry / meter (H/m) is the permeability constant used for air or ground.

IV. Field Analysis

As the torso and head are the most vulnerable parts of the body, electric and magnetic field assessment was carried out from 1m to 1.8 m above ground in the steps of 0.25 m, assuming the average height of line operator 1.8 m. The average of the field value assessed above is considered for safety evaluation.

A. Electric Field

Fig. 7, displays the electric field profile of 1200 KV AC single circuit line at mid span one meter above the ground level. Maximum value of field does not occur at the centre line as expected. There is hump at the centre line because of partial cancellation of three phase field .The field is maximum at mid span, 29 m away from centre line laterally and thereafter it decreases sharply [22-23].The field is symmetrical about the centre line. The maximum values of field exposure are 7.470 KV/m and 7.286 KV/m , at mid span 4 m and 1m above ground respectively. These are related to scenario number 2 & 1 for line operators working on ladder at 4m height and standing at mid span. The value of field is 4.732 KV/m at centre line.

The electric field goes on decreasing as one move away along the line from mid of the span (25 m ground clearance) towards the towers (37m) on both the sides, as ground clearance of conductors increases towards the towers [24]. Fig. 8, reflects the field profile at the edge of tower. The electric field values are 5.134 KV/m and 5.246 KV/m at 1 meter and 4 meter above the ground level which are related to scenario number 3 and 4 respectively for line workers, working at tower base. This exposure level for line workers is minimum.

The field values at the edge of ROW and 15 m laterally away from ROW are 5.386 KV/m and 3.261 KV/m respectively. This represents scenario numbers 5 & 6 which are for general public's living at ROW and 15 m away from it. The electric field increases vertically towards the conductors. It is 91.4 KV/m around the bundle conductor within radius of 2m as shown in fig 9.

Double circuit increases the reliability of power transfer and save land for line corridor. Fig.10 shows the electric field variation for 1200 KV D/C vertical configuration line. The field values are little less as compared to S/C line because of different configuration. The field exposure values for all six scenarios are tabulated in table III

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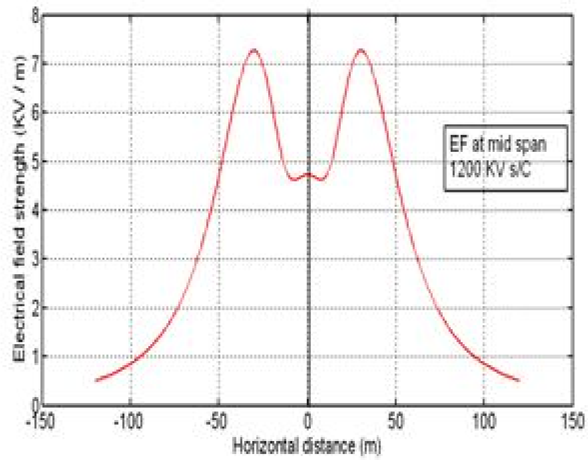

Figure 7. Electric field profile for S/C at mid span.

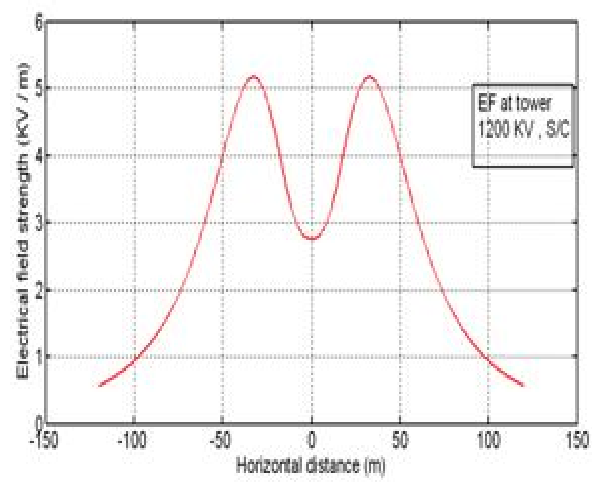

Figure 8. Electric field profile for S/C at tower.

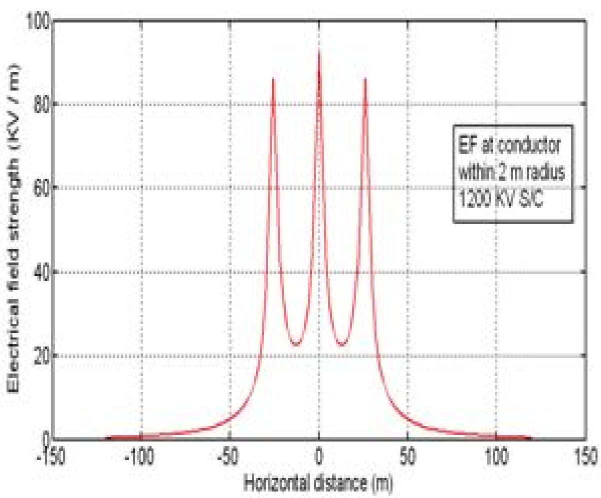

Figure 9. Electric field profile at bundle conductor with in 2m radius.

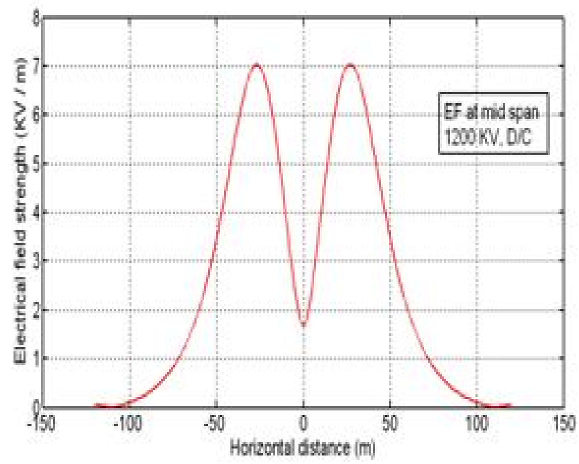

Figure 10. Electric field profile for D/C at mid span.

TABLE III.
ELECTRIC FIELD EXPOSURE FOR VARIOUS SCENARIOS

Scenario	Single circuit E (KV/ m)	Double circuit E (KV/ m)
1	7.286	7.13
2	7.470	7.23
3	5.134	3.48
4	5.246	3.53
5	5.386	4.20
6	3.261	2.03

B. Magnetic Field (MF)

The magnetic field analysis is carried out at full load current of 3800 A for both S/C horizontal line and D/C vertical line. The field is obtained at 1m and 4m above ground level. Fig. 11, shows the sample magnetic field for 1200 KV S/C line at mid span. The maximum value of field has occurred 29 m away from the centre line and thereafter goes on decreasing away from the centre line laterally. The maximum value of field exposure are 338.44 mG & 346.62 mG at mid span, 1m and 4m above ground level. These are related to scenario number 1& 2 respectively at mid span. The magnetic field curve is also symmetrical about centre line as in electric field [25]. The magnetic field around the tower base are 248.28 mG & 249.89 mG respectively related to scenarios 3 and 4. Field at ROW and 15m away from ROW are 246.81 mG and 149.14 mG respectively corresponds to scenarios 5 & 6 which are for general public's living in and around the ultra high voltage line.

The magnetic field scenarios for D/C vertical tower line are almost similar to S/C horizontal line. Fig. 12 displays the magnetic field of D/C line at mid span. Table IV provides the external electrical and magnetic field exposure for all scenarios.

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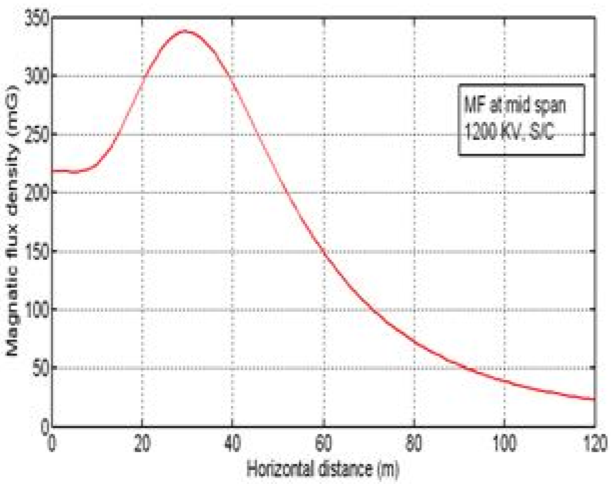

Figure 11. Magnetic field profile for S/C at mid span

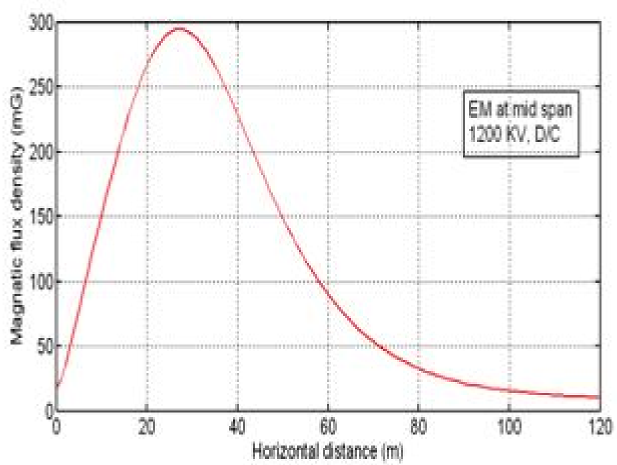

Figure 12. Magnetic field profile for D/C at mid span

TABLE IV.
Electric and Magnetic Field Exposure Values

Scenario	Single circuit		Double circuit	
	E (KV/ m)	M (mG)	E(KV/m)	M (mG)
1	7.286	338.44	7.13	298.32
2	7.470	346.62	7.23	302.49
3	5.134	248.28	3.48	146.85
4	5.246	249.28	3.53	149.18
5	5.386	246.81	4.20	179.08
6	3.261	149.14	2.03	85.32

V. Comparison with International Standards

The International Commission for Non-ionizing Radiation Protection of the International Radiation Protection Association (IRPA/ICNIRP),the Institute of Electronic and Electrical Engineers (IEEE) and the American Conference of Governmental Industrial Hygienists (ACGIH) had approved the exposure limit of 50/60 Hz based on electromagnetic field is as shown in table V.

A. *Electric Field*

Calculated values of electric field in section IV are compared with international standards shown in table V. The highest level of electric field exposure is at mid span where the ground clearance is minimum are 7.286 KV/m

TABLE V
Limit of Electric and Magnetic Field Exposure

Organisation	Exposure	E (KV/m)	M (mG)
IEEE-2002	1	20	27100
	2	5	9040
ACGIH-2008	1	25	10000
	2	--	--
ICNIRP-1998	1	8.33	4200
	2	4.2	830

and 7.470 KV/m for S/C line respectively. These are related to scenario number 1 & 2.These values are well below the limiting values given by all the standards in table V. Further, the scenario 3 and 4, around the tower base are also safe for both S/C and D/C. It is observed that the electric field exposure values for the general public, at the edge of ROW and 15 m laterally away are 5.386 KV/m and 3.261 KV/m respectively which is unsafe at ROW for general public's, which raises the question of safety and need to enforce the rules and regulations laid by central electricity authority and central government of India. Field exposure for D/C line at all scenarios is well below the limits set by the standards.

B. *Magnetic Field*

The exposure values of magnetic fields are highest at mid span where the ground clearance to conductors is minimum. For scenario 1 and 2 the field values are 338.44 mG and 346.62 mG respectively which are less than the standard limits. All exposed values shown in table IV, for all the scenarios for both S/C and D/C lines are quite less than the standard limits.

VI. Conclusion

Extensive analysis of EMF for UHV 1200 KV AC of S/C and D/C lines is carried out for safety of line operator and general public's living near the lines using MATLAB software .The system developed for analysis is based on combination of charge simulation and image method for electric field and Ampere's law for magnetic field. The exposures by electric and magnetic fields are presented graphically and also tabulated for various scenarios, which will be use full to power engineers and line operators.

The comparison of calculated values of EMF exposure with allowable limits set by international standards revels that the level of exposure to workers and general public's are well below the recommended limits for all scenarios considered by the authors except at the edge of ROW for general publics. However, use of proper mitigation technique to shield the

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electric field and enforcement of internationally accepted guidelines and regulations laid by the central electricity authority and central government might be the good solution.

References

[1] Agarwal H. K.Mukharji, A.K. Pal and P.Barua," Design and Development of 1200KV Transmission line and Substation Insulation Hardware Fittings Clamps& Connectors", CIGRE India journal Vol.1 issue 2, pp.10-18, 2012.

[2] Times of India,News paper, Nagpur Jan.10, 2011

[3] Z.Sienkiewicz,"Biological Effects of Electromagnetic Fields", IEE Power Engineering Journal, June 1998, pp.131-39.

[4] J. Swanson, " Magnetic Fields from Transmission Lines, Comparison of Calculations and Measurements", IEE Proc.-Gener. Transm. Distrih., Vol. 142, No. 5, , pp. 481-486 September 1995.

[5] A. S. Abdallah," Electric Fields from Transmission Lines nearby populated areas in Egypt",- Theory Versus Experiment . High Voltage Engineering Symposium. IEE ,No. 467 , pp. 2.119-2.222, August 1999.

[6] Korobkova, V. V., Uy. A. Morozov, M.D. Stolyarov, and Uy. A. Yakub.," Influence of the Electric Field in 500 and 750 kV Switchyards on Maintenance Staff and Means for its Protection. International Conference on Large High Tension Electric Systems. ClGRE , 1972.

[7] R. M. Radwan .Abdel-Salam, M. , Samy, M.M.," Electric Field Mitigation under Extra High Voltage Power Lines",IEEE Transactions on Dielectrics and Electrical Insulation Vol. 20, No. 1, pp.54-62, February 2013.

[8] S. Abdallah, "Electric Field from Transmission Lines nearby populated areas in Egypt-Theory Versus Experiment", part II, 11th Int'l. (Conf. Pub. No. 456), Vol. 2, pp. 222–229, Oct.1999.

[9] J. C. Salari, A. Mpalantinos, and J. I. Silva, "Comparative Analysis of 2-and 3-D Methods for Computing Electric and Magnetic Fields generated by Overhead Transmission Lines", IEEE Trans. Power Delivery, Vol. 24, , pp. 338-344, 2009.

[10] Hu Yu, Bai Baodong and Xie Dexin, "The Electro magnetic Field Distribution in the Human body under the Ultra-High Voltage Transmission Lines", IEEE pp. 2243-2246, 2002.

[11] International Commission on Non-Ionizing Radiation Protection:,"Guidelines limiting exposure to time-varying electric, magnetic, and electromagnetic fields (up to 300 GHz)", Health Physics, Vol. 74, No. 3,pp. 494-522, 1998.

[12] US Department of Energy (DOE) and Bonneville Power Administration (BPA), Electrical and Biological Effects of Transmission Lines – A Review, 2010.

[13] "IEEE Standard Procedure for Measurement of Power Frequency Electric and Magnetic Fields from AC Power Lines", IEEE Std 664-1994, New Yark, 1994.

[14] "IEEE Standard for Safety Levels with Respective Human Exposure to Electromagnetic Fields, 0-3 KHz", IEEE Std C95.6-2002, New Yark, 2002.

[15] American Conference of Governmental Industrial Hygienists, TLVs and BEIs, : ACGIH, 2008.

[16] Rakosh Das Begamudre, "Extra High Voltage AC Transmission Engineering" Edition, 3. Publisher, New Age, International Pub.,2006.

[17] Singer, H., H. Steinbigler, and P. Weiss, "A charge simulation method for the calculation of high voltage fields", IEEE Trans. PAS, v. 93, pp.1660-1668, 1974.

[18] W.H.Hayt and J.A. Buck, Engineering Electro magnetics (7th edition), McGraw-Hill, Singapore, 2006.

[19] Caola,R.J.and D.W.Deno, "Measurements of Electric and Magnetic Fields in and around homes near a 500-kV Transmission Line". IEEE Transactions on Power Apparatus and Systems PAS-102 (10), pp.3338-3347, 1983.

[20] Silva,J.M.et.al," Power Frequency Magnetic fields in homes",IEEE Trasaction on power delivery, Vol.PWRD, No.1 pp.465-478,Jan.1989.

[21] Evaluation of Electric & Magnetic Fields for the proposed Kemptown Substation, Enertech consultants, California Oct.2009.

[22] Zaffanella, L. E. and Deno, D. W.," Electrostatic and Electromagnetic Effects of Ultra High Voltage Transmission Lines", Palo Alto, California, Electric Power Research Institute (Final report EPRI EL – 802).1978.

[23] M.G.Unde and B.E. Kushare, "Analysis of Electro magnetic Fields of 1200kV UHV-AC Transmission Lines ". Un published.

[24] Sarmento, "Electric and Magnetic Fields in Overhead Power Transmission Lines ",, IEEE Transactions Latin America Vol.10, (04), pp 1909-1915, 2012.

[25] A Report on ,"Electric and Magnetic Fields from Overhead Power Lines", A Summary of Technical and Biological Aspects by Eskom Holdings Ltd, 2006.

DOI: 01.IJEPE.4.3.18